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**DANISH GEOTECHNICAL SOCIETY
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Measuring undrained shear strength using CPT and Field Vane

By

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SUMMARY

This paper presents the results of CPT's and Field Vane tests from two small test areas with different soils, Glacial Till and Yoldia Clay. An average of $N_k = q_t/c_v$ for the Yoldia Clay is 7.7 with a standard deviation of 0.7. The average of N_k for the Glacial Till is 9.7 with a standard deviation of 2.2.

INTRODUCTION

An attempt has been made to find a correlation between cone resistance q_t and undrained shear strength in a simple linear form /1/.

$$q_t = N_k \cdot c_v$$

where q_t = cone resistance. N_k = cone factor. c_v = undrained shear strength obtained by Field Vane.

Tests made elsewhere have produced a cone factor N_k with a very wide range $5 < N_k < 35$. Usually when q_t is related to c_v there is only one or very few borings with vane tests to which the CPT results can be related. This might be one of the reasons for the large scatter observed.

This paper presents the results from two test sites in Denmark with different clays, Rørdal near Aalborg and Purhus near Randers. Once the test areas were marked out CPT's and Field Vane tests were performed as close to each other as possible in order to ensure reliability. The exact test positions at Rørdal can be seen on Fig. 1.

This large number of tests forms the basis for a statistical evaluation of q_t and c_v , thereby making it possible to find an approximate average value for N_k and an estimate of the variation of N_k for these two soils.

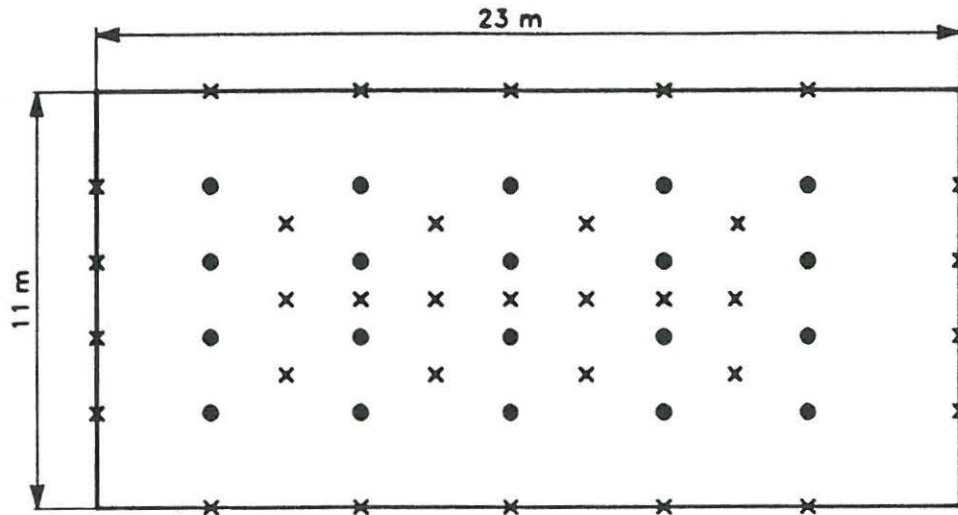


Fig. 1: Test area at Rørdal. ● CPT (to depths of 2 to 3 meters). x vane test at four depths 0.5, 1.0, 1.25, and 1.5 m.

TEST EQUIPMENT

CPT

The cone penetrometer used is the A.P. van den Berg piezocone. It measures cone resistance q_c , sleeve friction f_s , and pore pressure u . The cone has a 60° apex angle, cross sectional area of 10 cm^2 , and a friction sleeve area of 150 cm^2 . The pore pressure filter is located just behind the cone. The cone resistance is afterwards corrected for the pore pressure acting on the area behind the cone /3/ making the effective cone area 10 cm^2 .

$$q_t = q_c + (1 - a)u$$

where q_t = corrected cone resistance. q_c = measured cone resistance. u = measured pore pressure a = effective area ratio (0.7 found by calibration for this specific cone).

The rate of penetration was 2 cm/sec. in all tests.

Field Vane

The Field Vane is the Danish type A vane with a diameter of 3.3 cm and height of 6.6 cm. The vane is hammered into the ground and the vane test is performed immediately afterwards. The maximum shear should be reached within and as near 2 min. as possible.

TEST SITES

Rørdal, Aalborg (Yoldia Clay)

The soil on this site was deposited in the ice sea which covered parts of northern Denmark about 10,000 years ago. The clay is rather fat, inorganic with very thin stripes (approximately 1 mm) of silt, sand, and chalk. The Yoldia Clay has been classified at three depths

0.5, 1.0 and 1.5 m. At each depth six samples were used to obtain the consistency limits. At least three samples were used for the estimation of the other classification properties. The average soil properties for each depth can be seen in table 1.

Depth [m]	d_s	w [%]	w_L [%]	w_p [%]	I_p [%]	I_c	Clay cont. [%]	Activity	e	γ [kN/m ³]
0.5	2.78	31.1	62.7	26.3	36.4	0.87	58	0.63	0.86	19.2
1.0	2.71	29.6	59.6	24.7	34.8	0.85	59	0.59	0.87	19.2
1.5	2.76	33.3	65.1	26.2	38.9	0.82	62	0.63	0.90	19.1

Table 1: Classification properties for the Yoldia Clay in Rørdal.

Purhus, Randers (Glacial Till)

The clay on this site is a Glacial Till, unsorted, described as yellowish-brown, sandy to very sandy, with no chalk, and gravelly. It is a deposit from the Weichsel ice 10,000 to 15,000 years ago. The soil properties were classified by "Statens Vejlaboratorium", Denmark, in a boring 10 meters from the test area. The results are listed in table 2.

Depth [m]	d_s	w [%]	w_L [%]	w_p [%]	I_p [%]	I_c	Clay cont. [%]	Activity	e	γ [kN/m ³]
1.2 - 2.0	2.73	15.2	23.5	15.0	8.5	0.98	15	0.57	0.41	22.3

Table 2: Soil properties for the Glacial Till at Purhus, classified by Statens Vejlaboratorium.

TEST RESULTS

When comparing cone penetration tests and vane tests q_t and c_v are both assumed to represent the soil strength at a given point. The problem that always exists when comparing one test type to another is that the measurements are not obtained at exactly the same point. By assuming that the soil properties do not change discontinuously over the area, we can use an estimation technique called "Kriging" to estimate the values between the measured points. Kriging is a stochastic interpolation method that accounts for the uncertainties associated with soil properties [2].

In the following Kriging is used to estimate the distribution of both q_t and c_v over the area. By dividing the q_t -surface with the c_v -surface, the variation of N_k is found.

Yoldia Clay

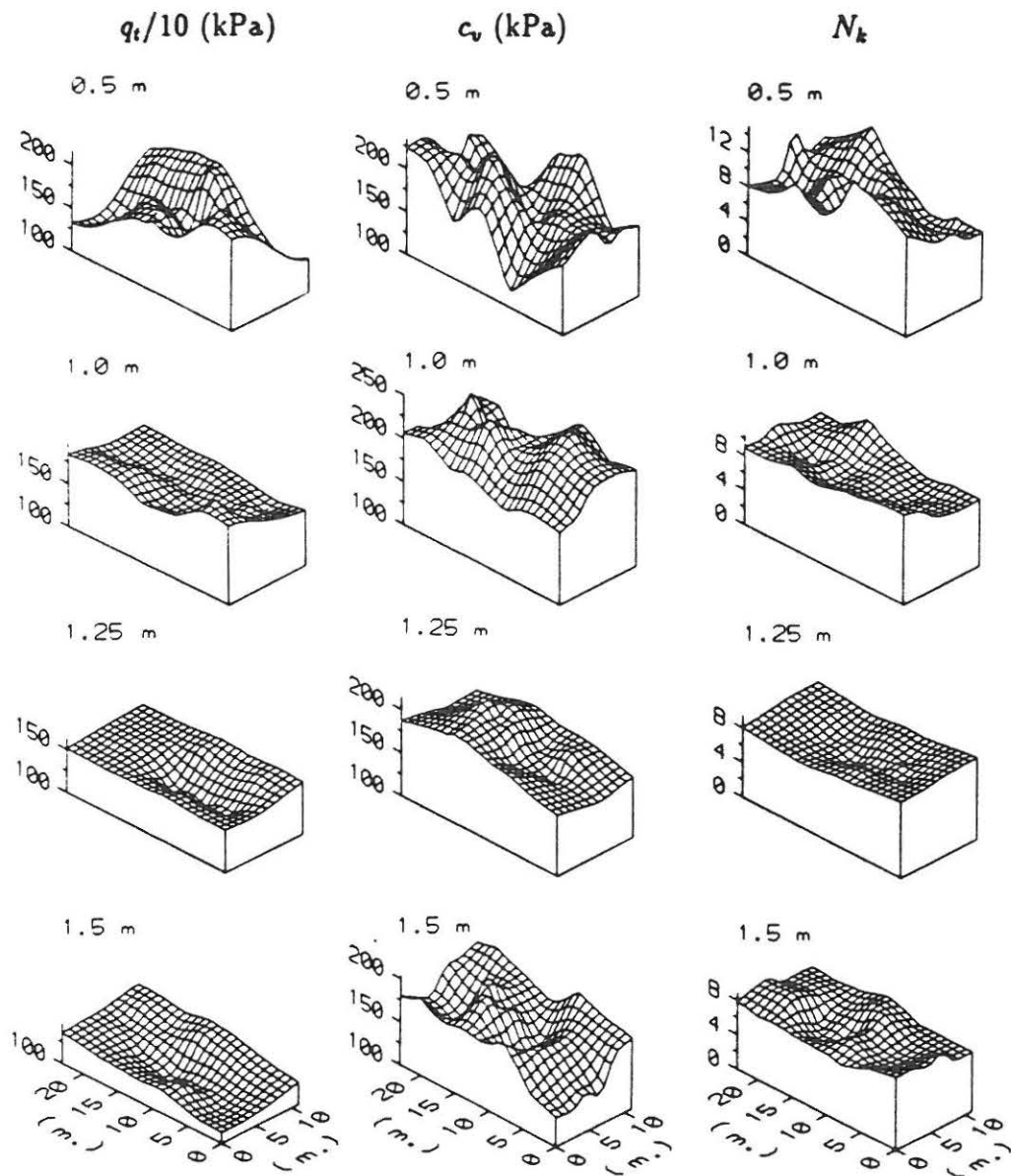


Fig. 2: $q_t / 10$ (kPa); c_v (kPa) and N_k in four depths at Rørdal, 0.5 m, 1.0 m, 1.25 m, and 1.5 m.

	$q_t / 10$ (kPa)				c_v (kPa)				N_k			
	0.5m	1.0m	1.25m	1.5m	0.5m	1.0m	1.25m	1.5m	0.5m	1.0m	1.25m	1.5m
n	20	20	19	19	31	30	16	32	34	34	34	34
\bar{x}	164	167	146	129	188	211	188	174	8.7	7.7	7.7	7.5
s_x^2	835	143	125	126	1117	515	289	495	2.9	0.4	0.4	0.8
s_x	29	12	11	11	33	23	17	22	1.7	0.7	0.6	0.9
m	170	165	150	130	190	212	190	175	8.8	7.6	7.7	7.4
v	0.18	0.07	0.08	0.09	0.18	0.11	0.09	0.13	0.20	0.09	0.08	0.12

Table 3: Statistical properties for Yoldia Clay at Rørdal. n = number of samples. \bar{x} = sample mean. s_x^2 = variance. s_x = std. deviation. m = median. v = coefficient of variation.

Glacial Till

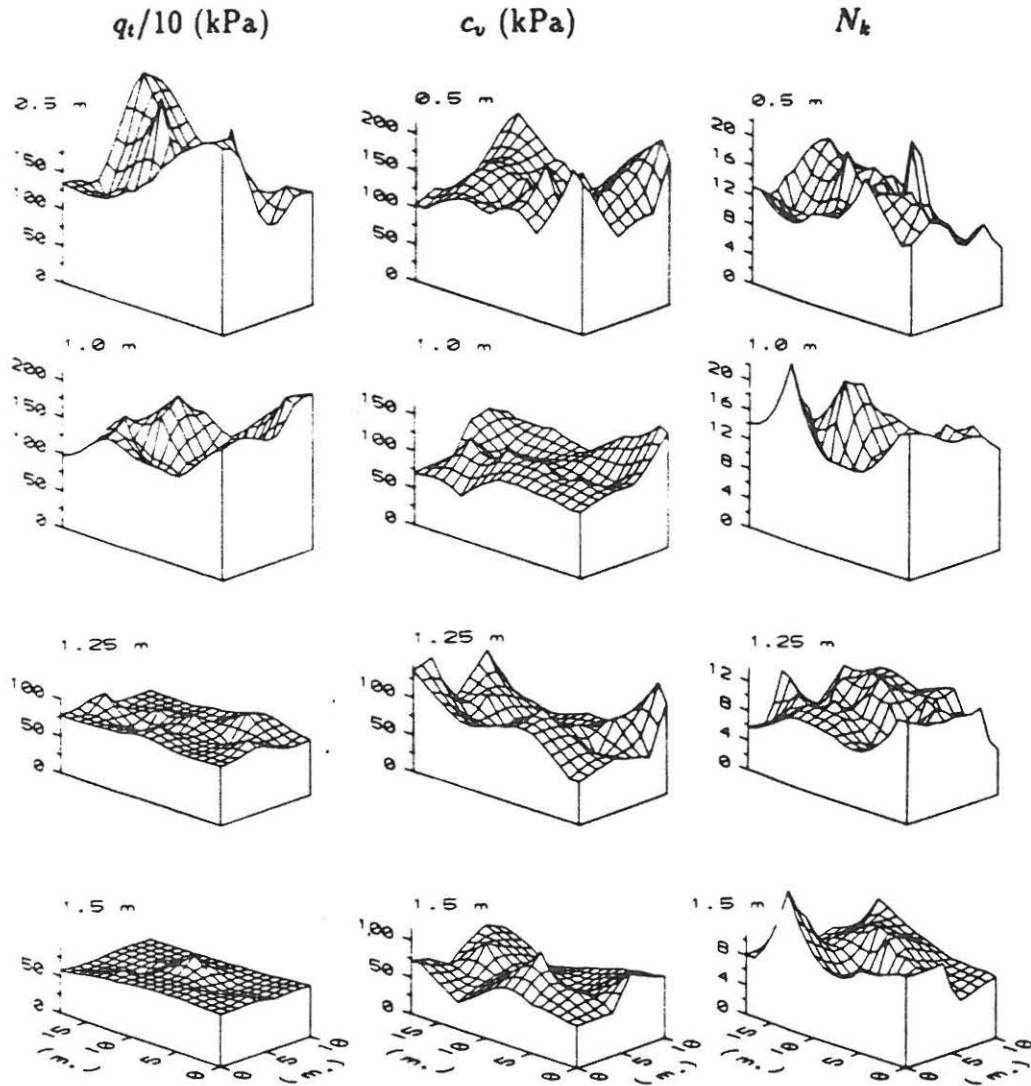


Fig. 3: $q_t / 10$ (kPa); c_v (kPa) and N_k in four depths at Purhus, 0.5 m, 1.0 m, 1.25 m, and 1.5 m.

	$q_t/10$ (kPa)				c_v (kPa)				N_k			
	0.5m	1.0m	1.25m	1.5m	0.5m	1.0m	1.25m	1.5m	0.5m	1.0m	1.25m	1.5m
n	20	20	20	19	25	27	27	27	40	40	39	38
\bar{x}	157	120	77	66	138	100	83	69	12.1	12.0	9.9	9.5
s_x^2	2928	1893	148	74	1527	469	691	308	13.5	22.1	6.0	3.5
s_x	54	44	12	9	39	22	26	18	3.6	4.7	2.4	1.9
m	135	105	75	65	131	99	73	66	11.5	10.2	10.4	9.4
v	0.34	0.37	0.16	0.14	0.28	0.22	0.31	0.26	0.30	0.39	0.24	0.20

Table 4: Statistical properties for the Glacial Till at Purhus. n = number of samples. \bar{x} = sample mean. s_x^2 = variance. s_x = std. deviation. m = median. v = coefficient of variation.

DISCUSSION

CPT and Field Vane tests have been performed in two small test areas with different soil types, Glacial Till and Yoldia Clay.

The greatest standard deviations are measured in the upper layers probably due to crust formation in summer. The compaction of the clay depends on the capillary forces which vary much over the area.

The depth at which the capillary forces influence test results varies according to soil types, possibly 1.0 m in Glacial Till and 0.5 m in Yoldia Clay.

When not taking the test results in the crust zone into account the average of N_k is approximately 7.7 for Yoldia Clay and 9.7 for Glacial Till. These values compare well with other N_k values registered for similar soils, Yoldia Clay in Aalborg ($N_k = 8$) and Glacial Till in the Great Belt ($N_k = 10$) /1/. The standard deviation for N_k in Yoldia Clay is 0.7 and 2.2 for N_k in Glacial Till.

The coefficient of variation (s_x/\bar{x}) which signifies the uniformity of the test results is 0.1 for N_k in Yoldia Clay. The test results from Glacial Till show a coefficient twice that of Yoldia Clay (0.2) as can be expected due to lack of uniform consistency of Clay Till which contains both stones and gravel.

On the two test sites there is a tendency for N_k to decrease with depth of penetration. The most likely explanations are:

1. The soil contains non-fully saturated clay because it lies above ground water level which is the case for the Clay Till examined at Purhus and the Yoldia Clay above 1 m depth at Rørdal. Yoldia Clay contains sand/silt stripes and Clay Till has a high sand content. It appears, therefore, that degree of saturation can affect N_k .
2. As the vane is hammered into the ground any friction on the vane rod will increase with depth penetration, thereby creating a higher c_v value and consequently lower N_k values.

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